Nephological conjuring: Do better clouds lead to better cloud scores?

Cyril Morcrette

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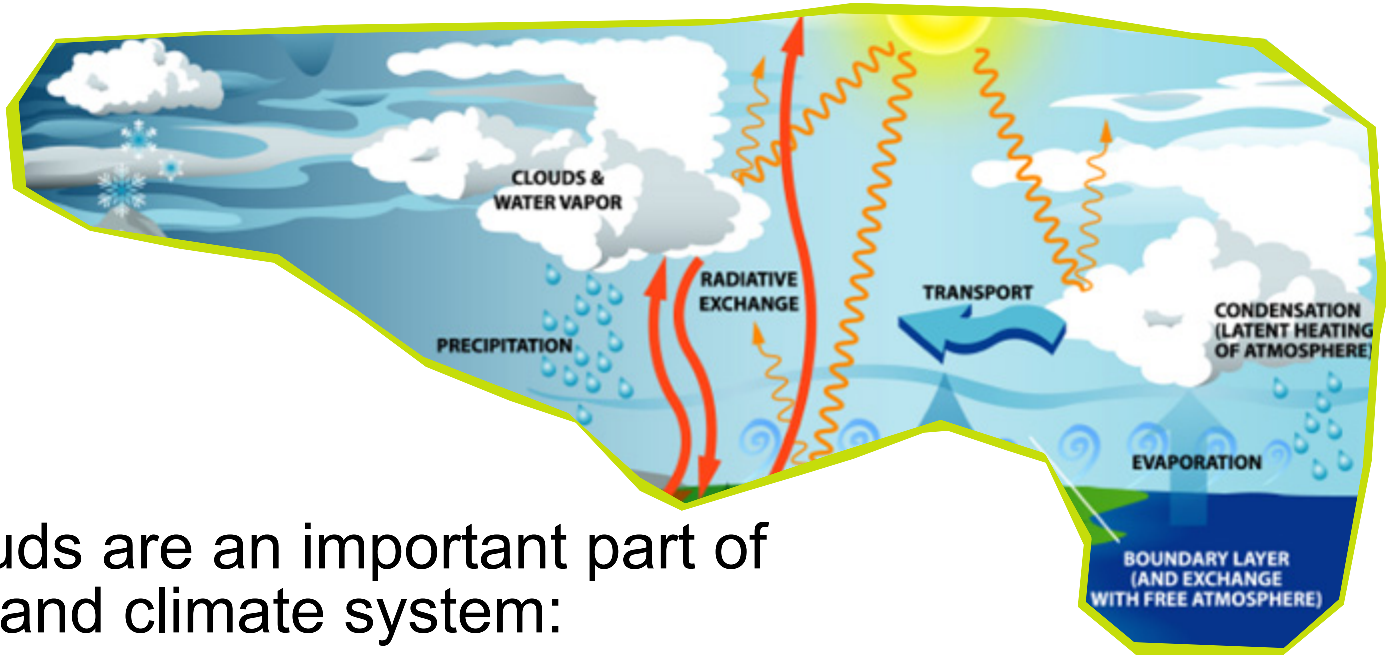
Motivation

Why clouds are important



Why clouds are an important part of weather and climate system:

- latent heat release
- radiative balance
- precipitation
- surface temperature

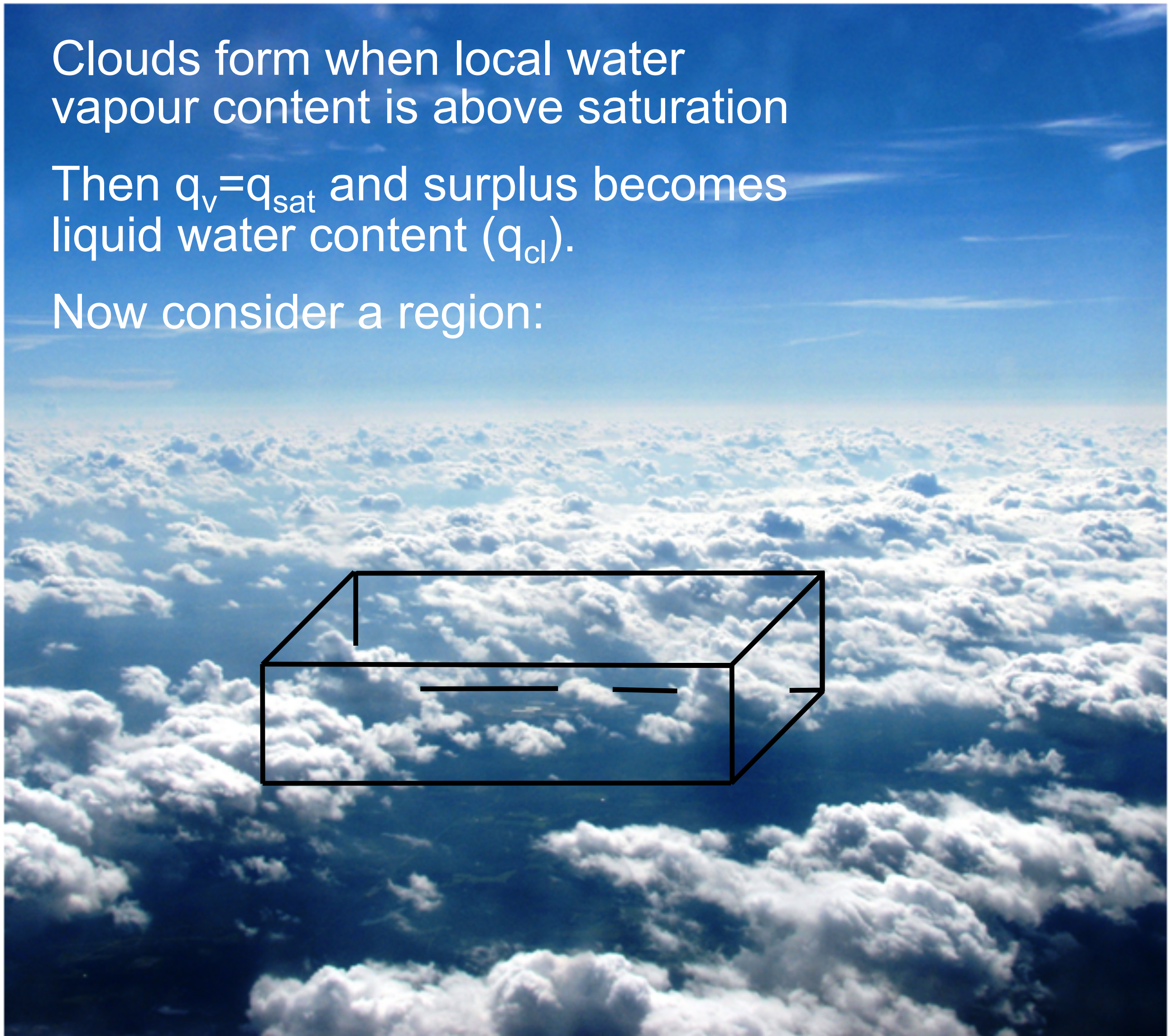
How clouds are represented in weather and climate model

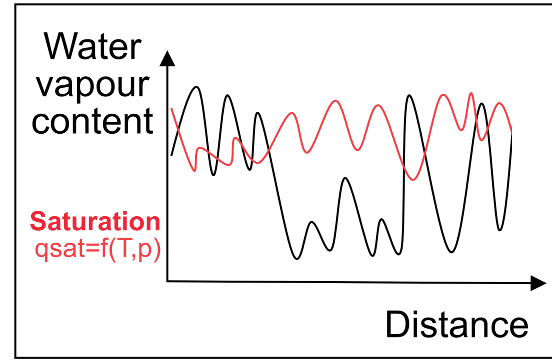
Cloud formation

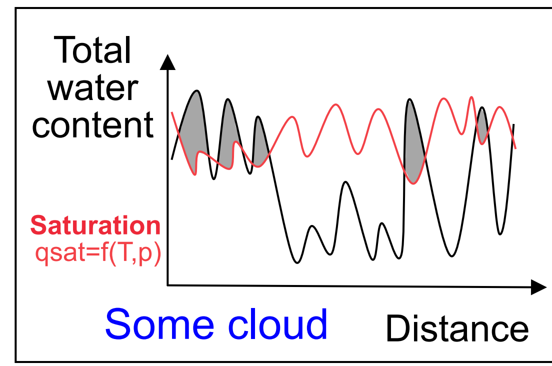
Clouds form when local water vapour content is above saturation

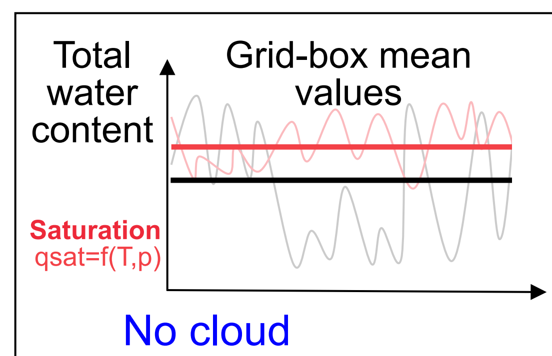
Then $q_v = q_{sat}$ and surplus becomes liquid water content (q_{cl}).

Now consider a region:









Diagnostic Cloud Schemes

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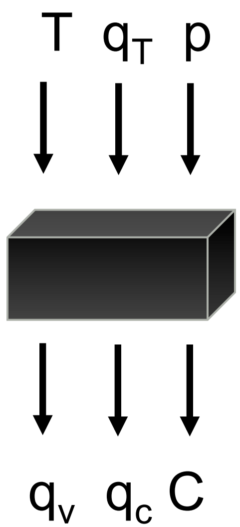
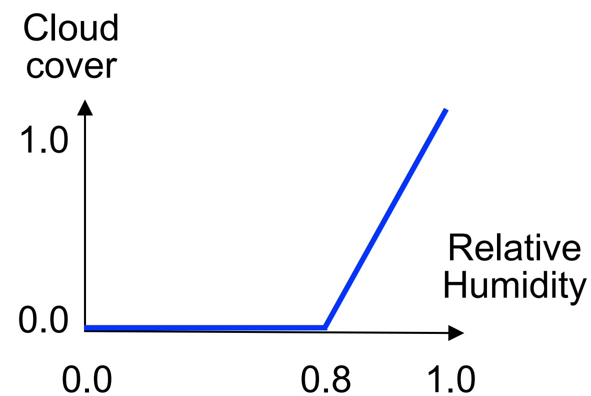
A diagnostic scheme



Then forget everything and start again next timestep

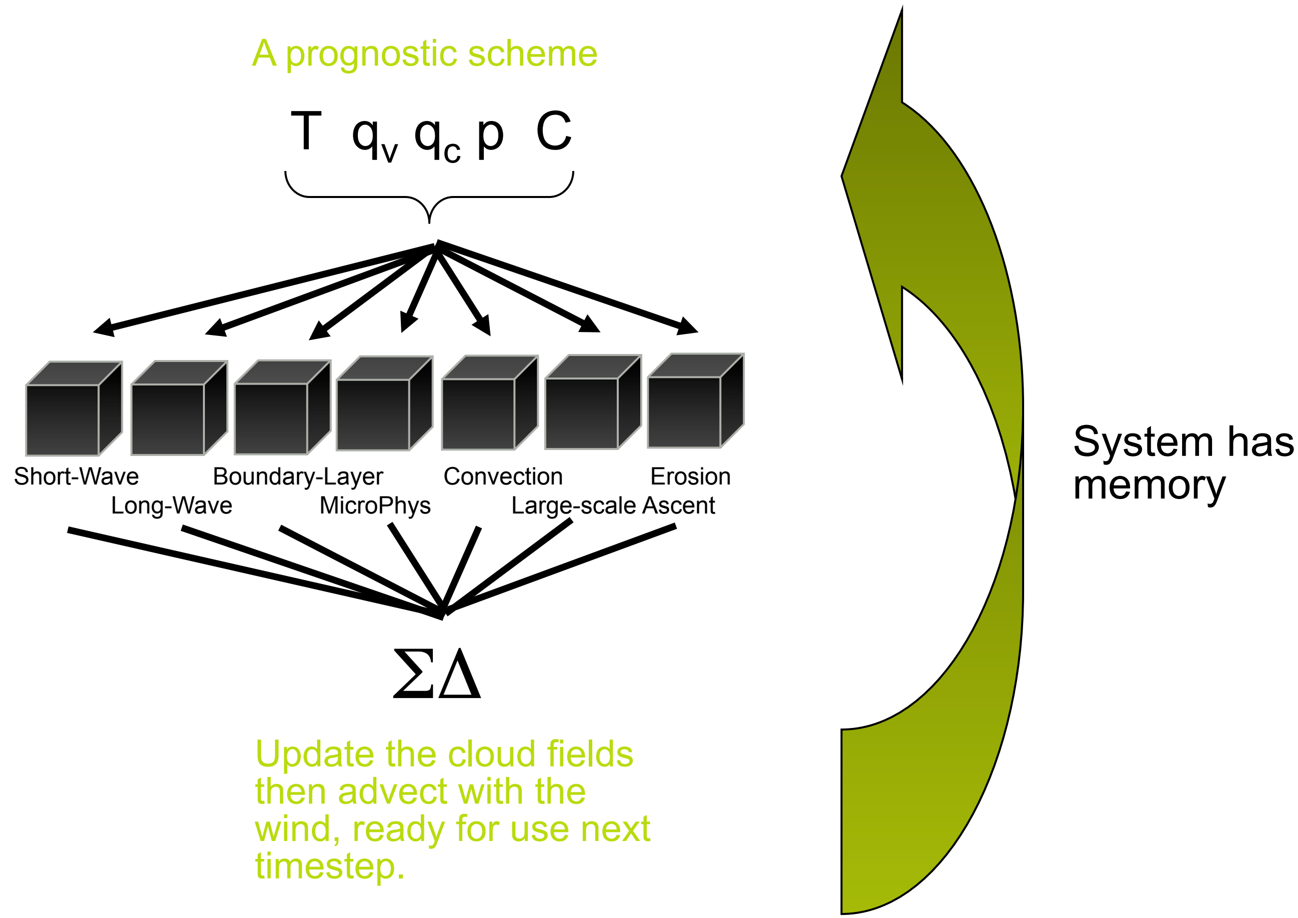
A very simple cloud fraction scheme.



Diagnostic scheme in Unified Model has more complexity, but ultimately for a given atmospheric state (T,q,p) there is only one possible value of cloud cover and liquid water content.

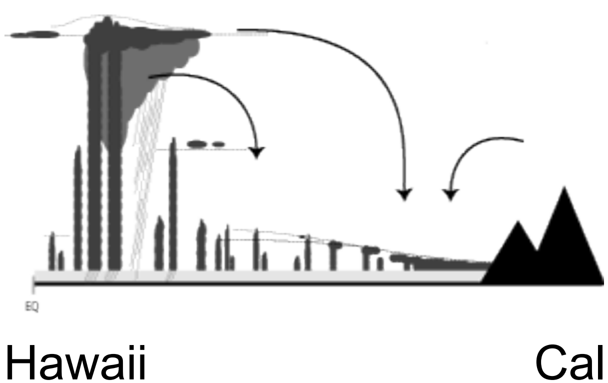
- However observations suggest that the same thermodynamic state (T,q,p) can be associated with different cloud cover and condensate amounts.
- So need to have a system where the clouds at a given point is the result of lots of different processes acting on the cloud and modifying it through-out its lifetime.
- Allows same thermodynamic state to have different cloud in it, depending on what has happened before.

Prognostic Cloud Schemes

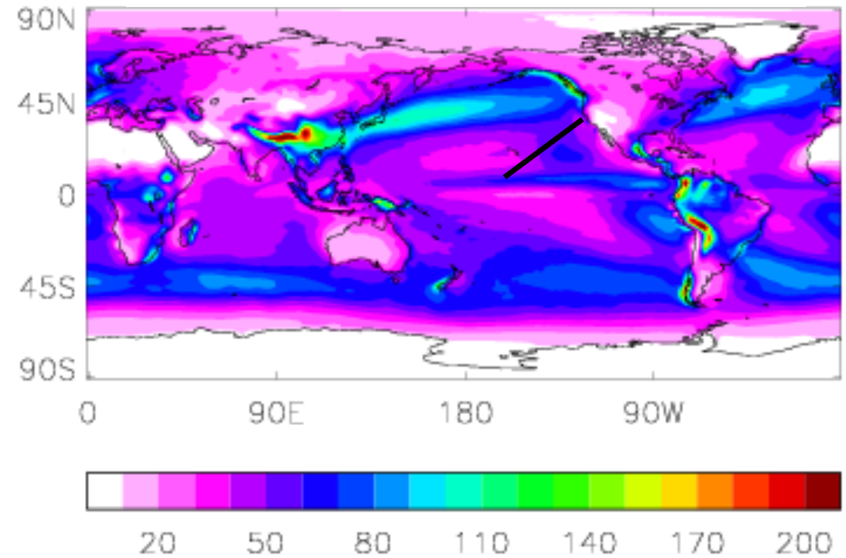


Cross-section through Hadley Circulation

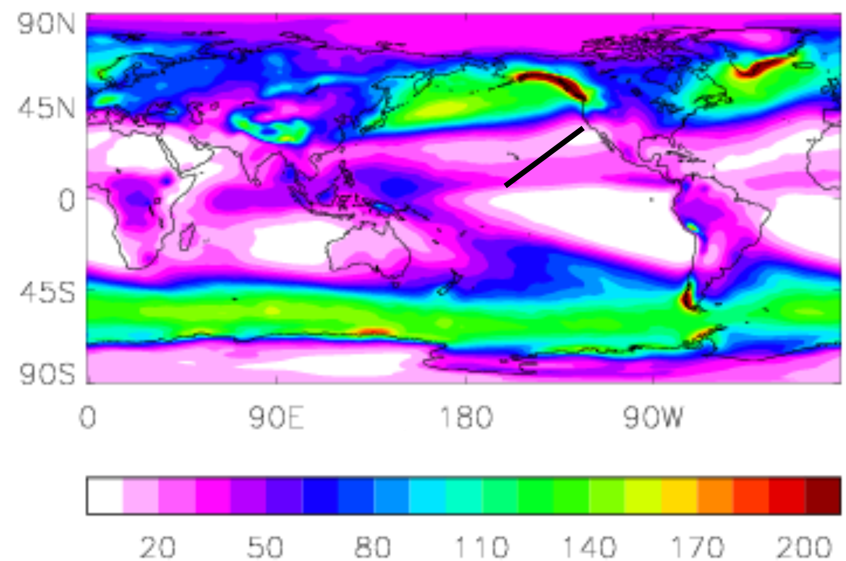
- Stratocumulus (off coast of California)
- Cumulus
- Cumulonimbus (south of Hawaii)



Liquid Water path (g m-2)



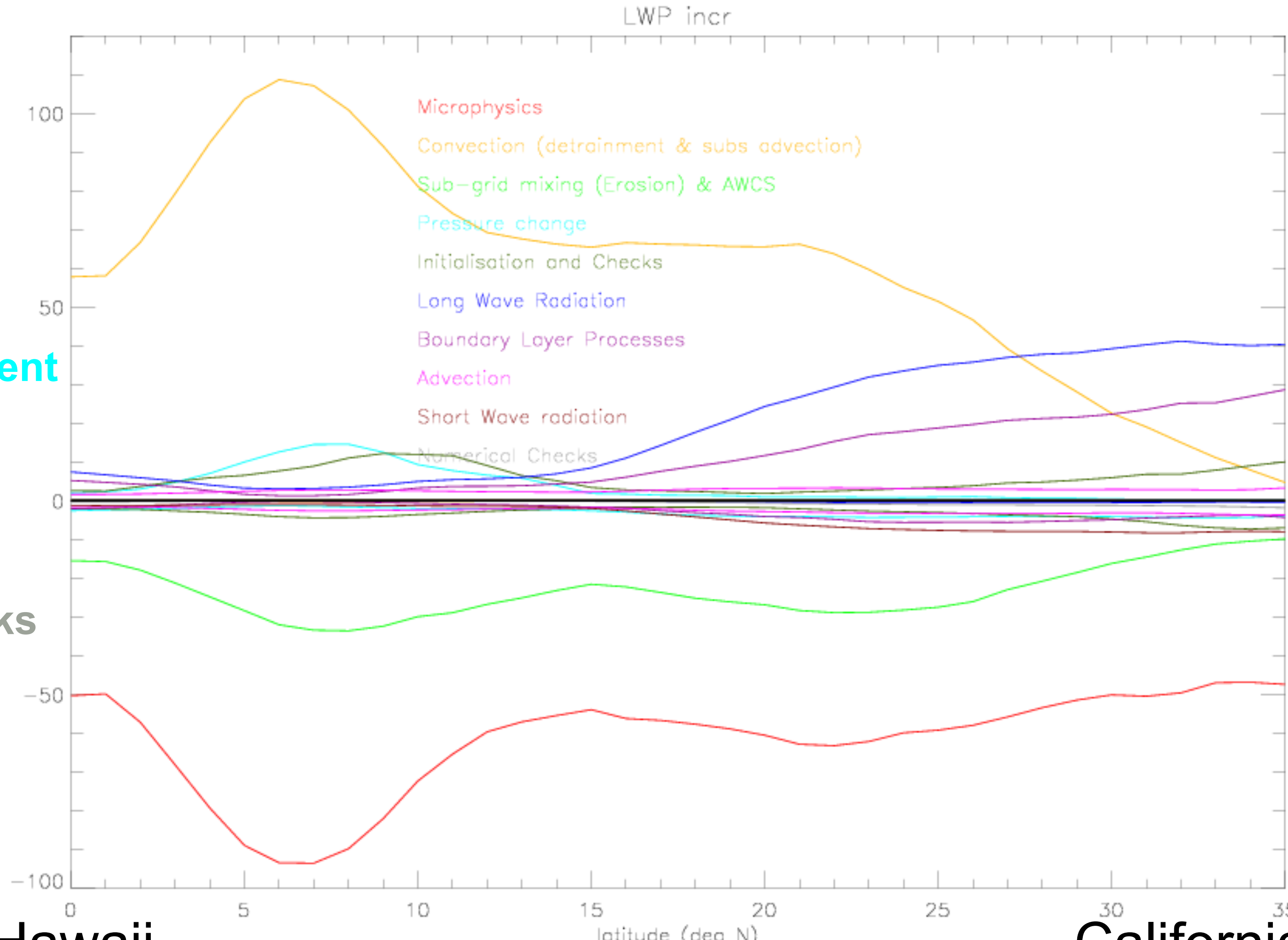
Ice Water path (g m-2)



Pacific Cross-Section: Liquid Water Path Increments

[g m-2 hr-1]

Microphysics
Convection
Erosion
Large-scale ascent
Initialization
Long-wave
Boundary-layer
Advection
Short-wave
Numerical checks



Hawaii

California

Morcrette and Petch (2010) *QJRMS*, **136**, 2061-2073

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Evaluating cloud forecasts

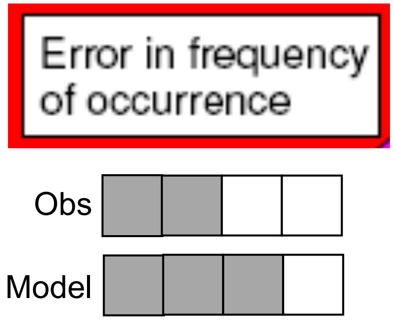
- Imagine you have 2 sets of cloud forecasts:
  - 2 different models or
  - same model, 2 different cloud parametrization schemes

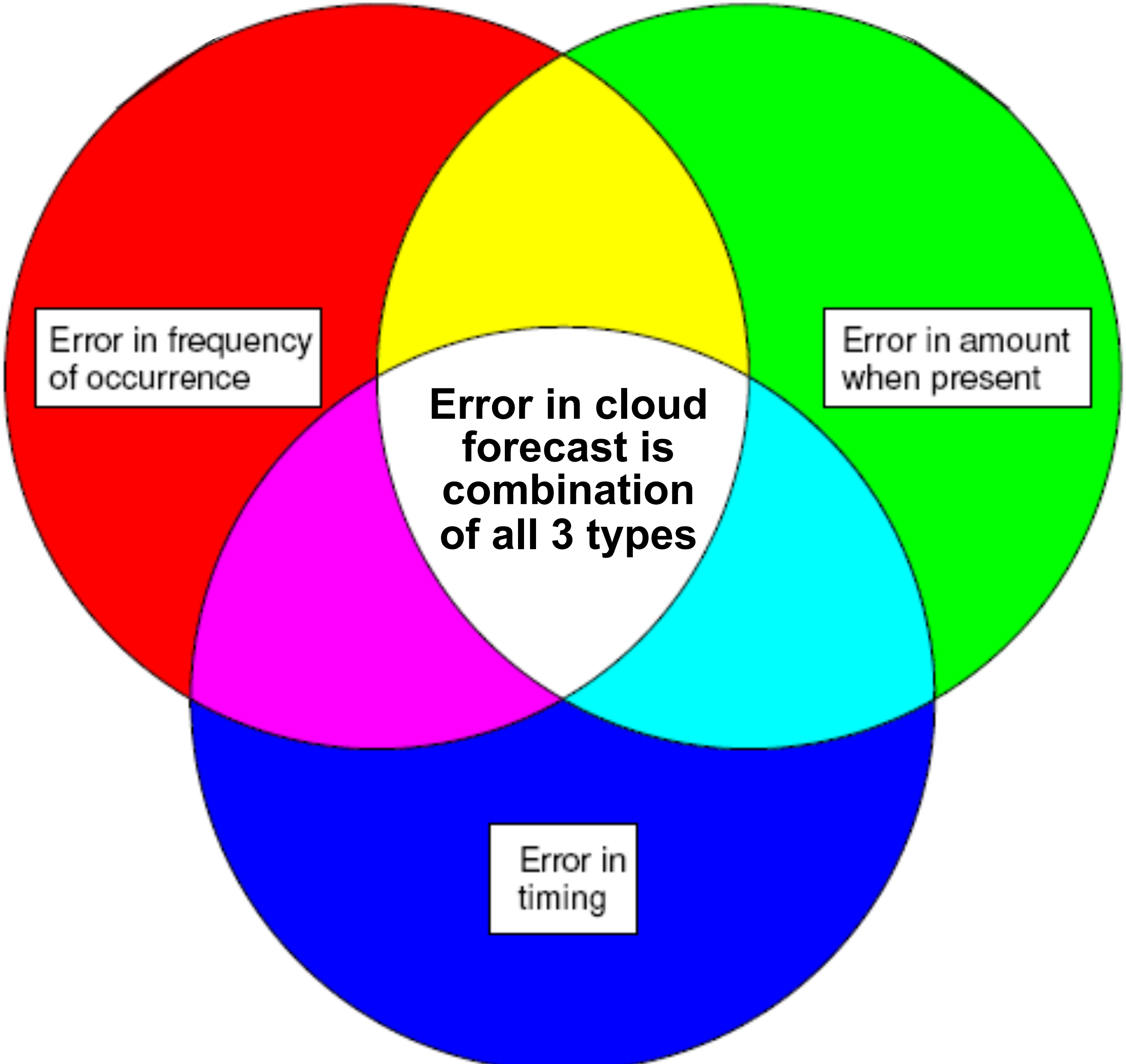
- **Which one is "better" ?**

- "Better" one has smaller errors.

- But there are different types of cloud errors…

Cloud errors can be:




Error in frequency
of occurrence
Error in amount
when present
Error in cloud
forecast is
combination
of all 3 types
Error in
timing

What do we really care about?

Climate

- Average impact of cloud
- Radiative impact of clouds depends on FOO and AWP (can be non-linear).
- Willing to accept some error in AVG, FOO or AWP if it makes climatological radiative balance better.
- So can get correct radiative impact due to incorrect mean and compensating errors in FOO and AWP.
- Do not really care about timing.

Weather Forecasting

- Correct FOO
- Correct AWP
- Timing is crucial
- Not too worried if radiative balance is out on long timescale.

Here is an evaluation of cloud forecasts which aims to separately quantify each of these types of cloud errors.

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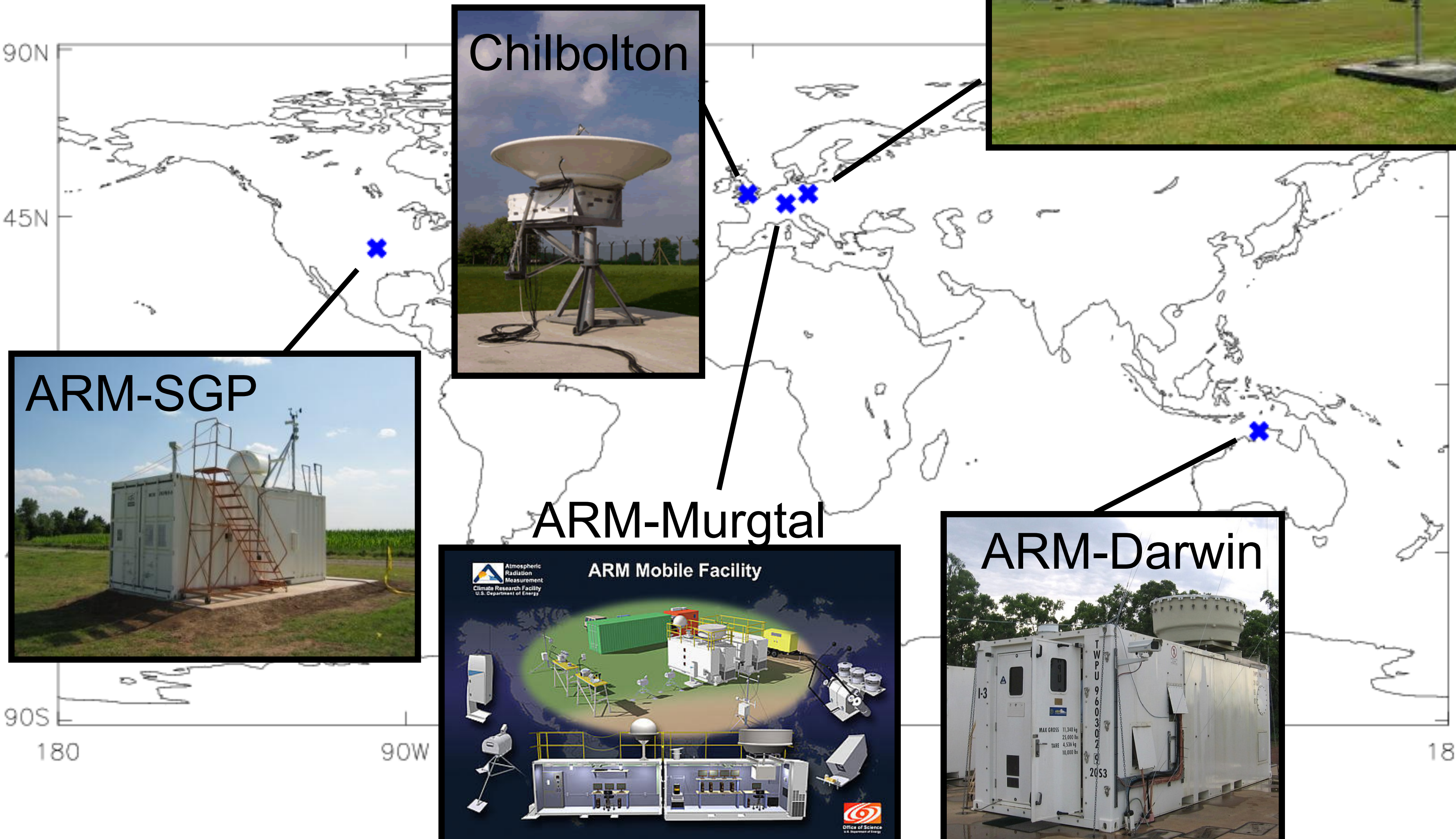
Need some observations. Use cloud-observing sites



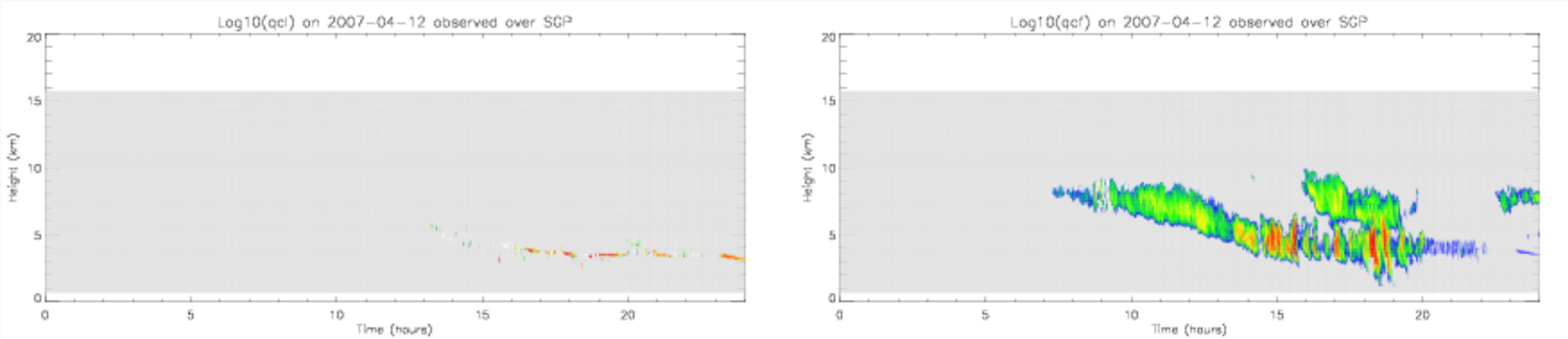
Photos from respective observatory websites.

Methodology for comparing NWP to Cloud-Net or ARM

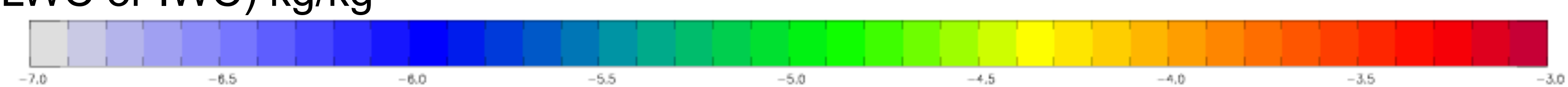
- April, July, October, December 2007 seem like good periods as sample different seasons and observations are available from 5 sites:
    - Chilbolton (UK)
    - Lindenberg (Germany)
    - Darwin (Australia)
    - Southern Great Plains (SGP, Oklahoma, US)
    - Murgtal (Germany)

- Run the NWP global model from ECMWF ERA-interim analyses.
- Run 2 forecasts from 12Z (one using Smith *diagnostic* cloud scheme and one using *prognostic* PC2)
- 36 hr forecast. Look at output from 00Z to 24Z (i.e. T+12 to T+36).
- Repeat for all the days of each month for each of the 4 months considered.
- For the model column over each of the observation sites, at each timestep during the forecast, output the following:
    - Liquid and ice cloud fraction
    - Temperature
    - Wind speed.

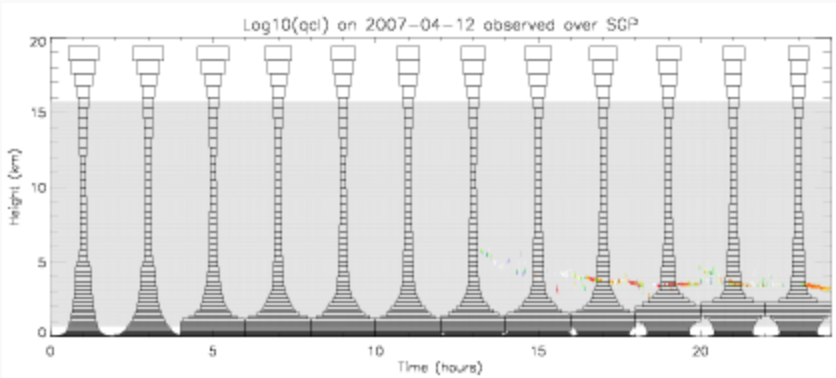
Example for Southern Great Plains

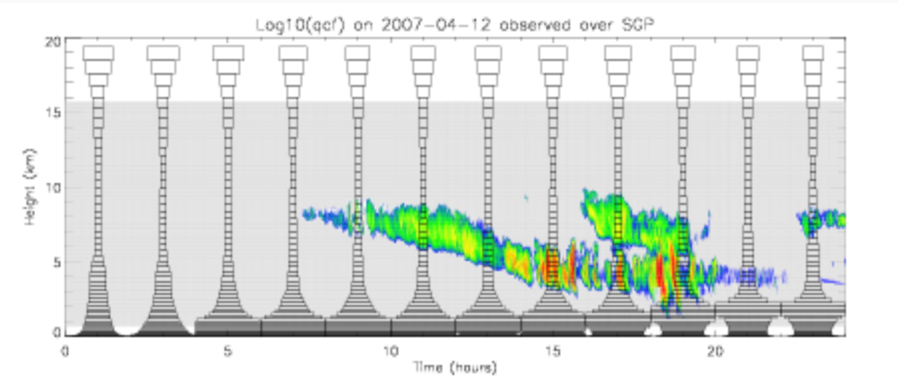


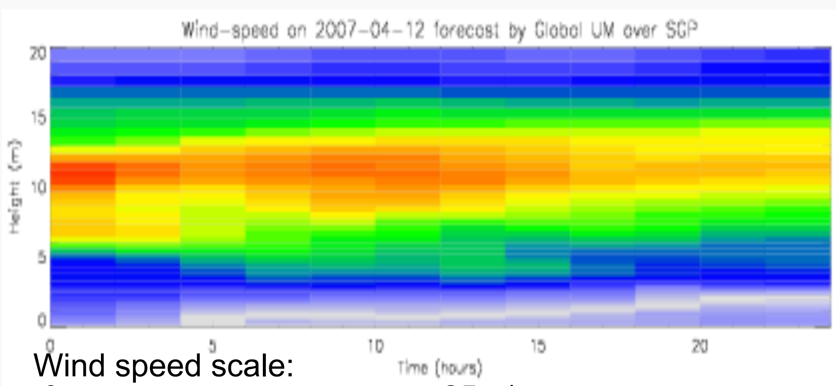
Log10(LWC or IWC) kg/kg



Example for Southern Great Plains

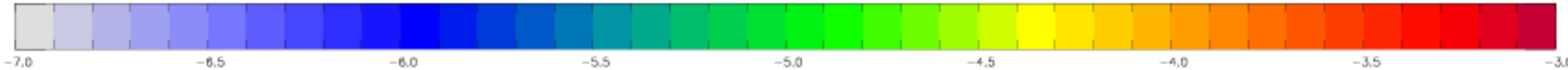




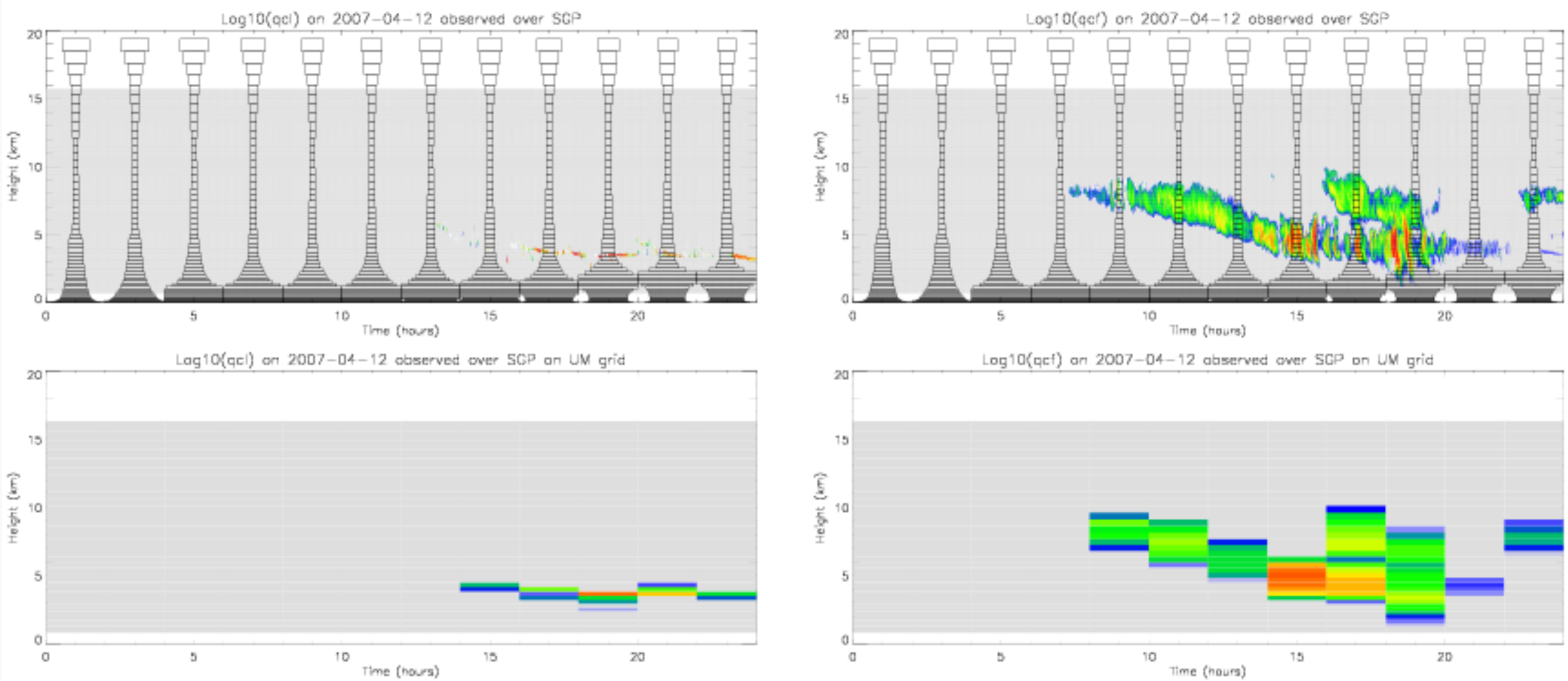


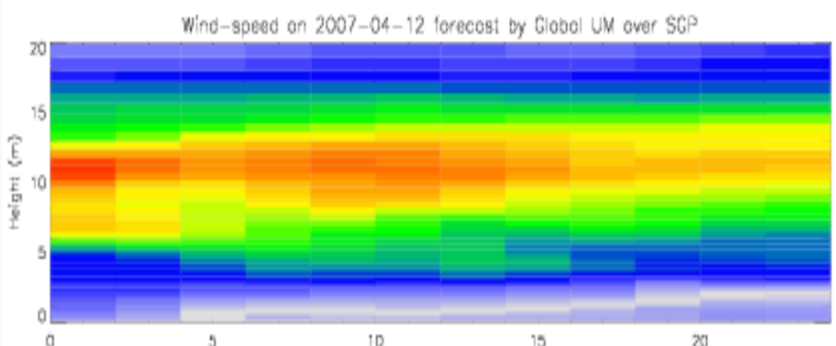
Wind speed scale:

0 25m/s 50m/s 75m/s 100



Example for Southern Great Plains



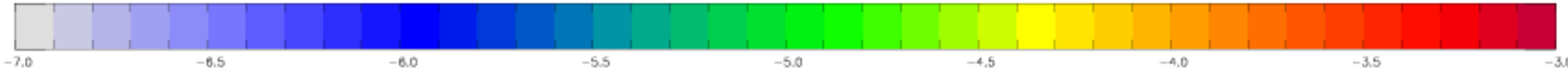


To ensure fair comparison:

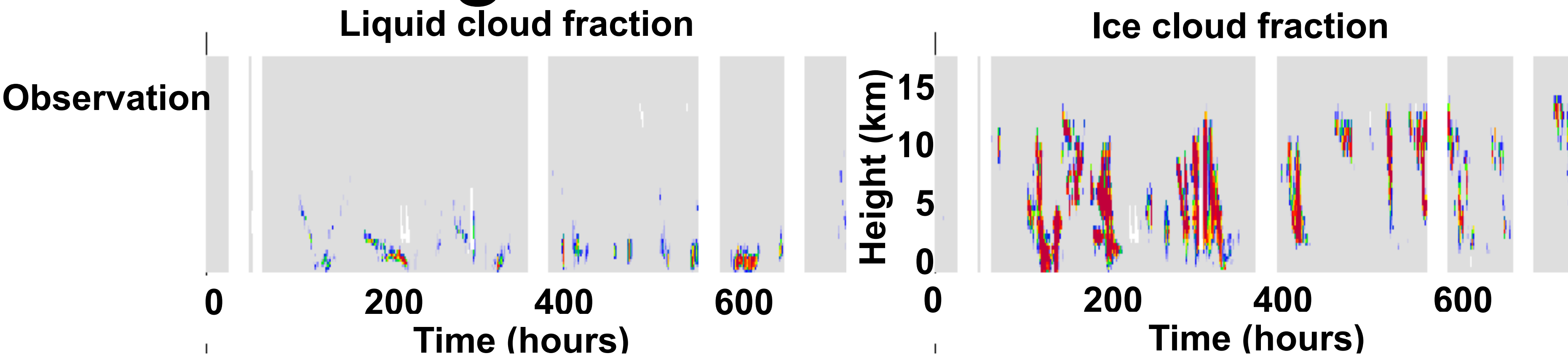
Filter out the ice cloud in the model that would be too thin for the radar to see.

Wind speed scale:

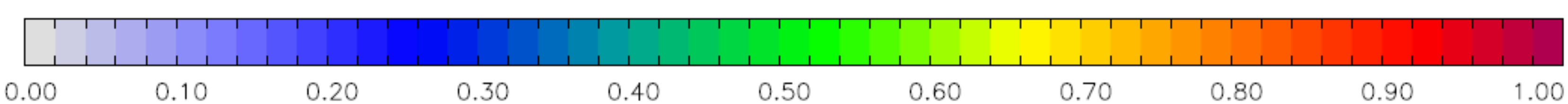
0 25m/s 50m/s 75m/s 100



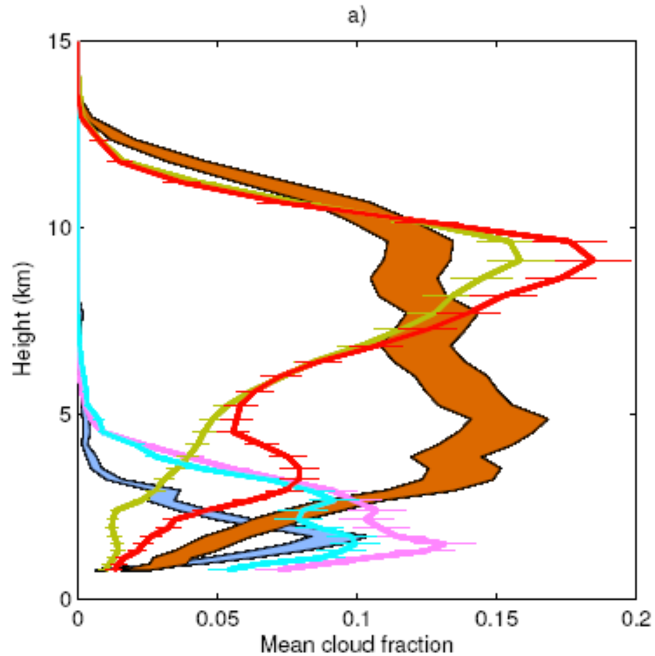
Time-height cross-sections

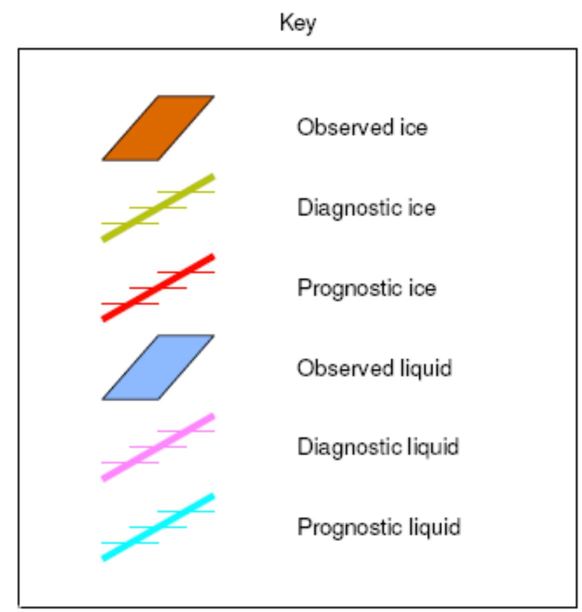


April
2007
SGP



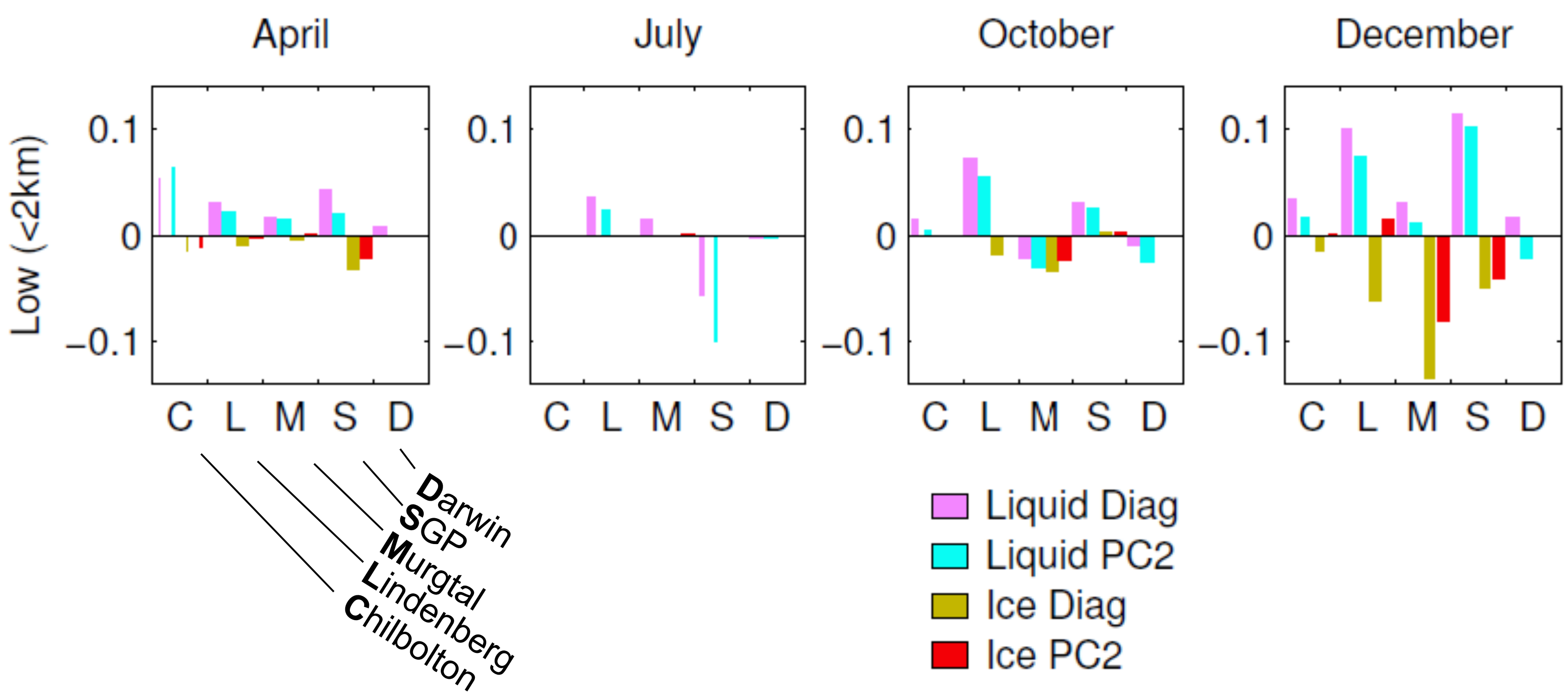
Morcrette, O'Connor and Petch (2011) *QJRMS* DOI:10.1002/qj.969





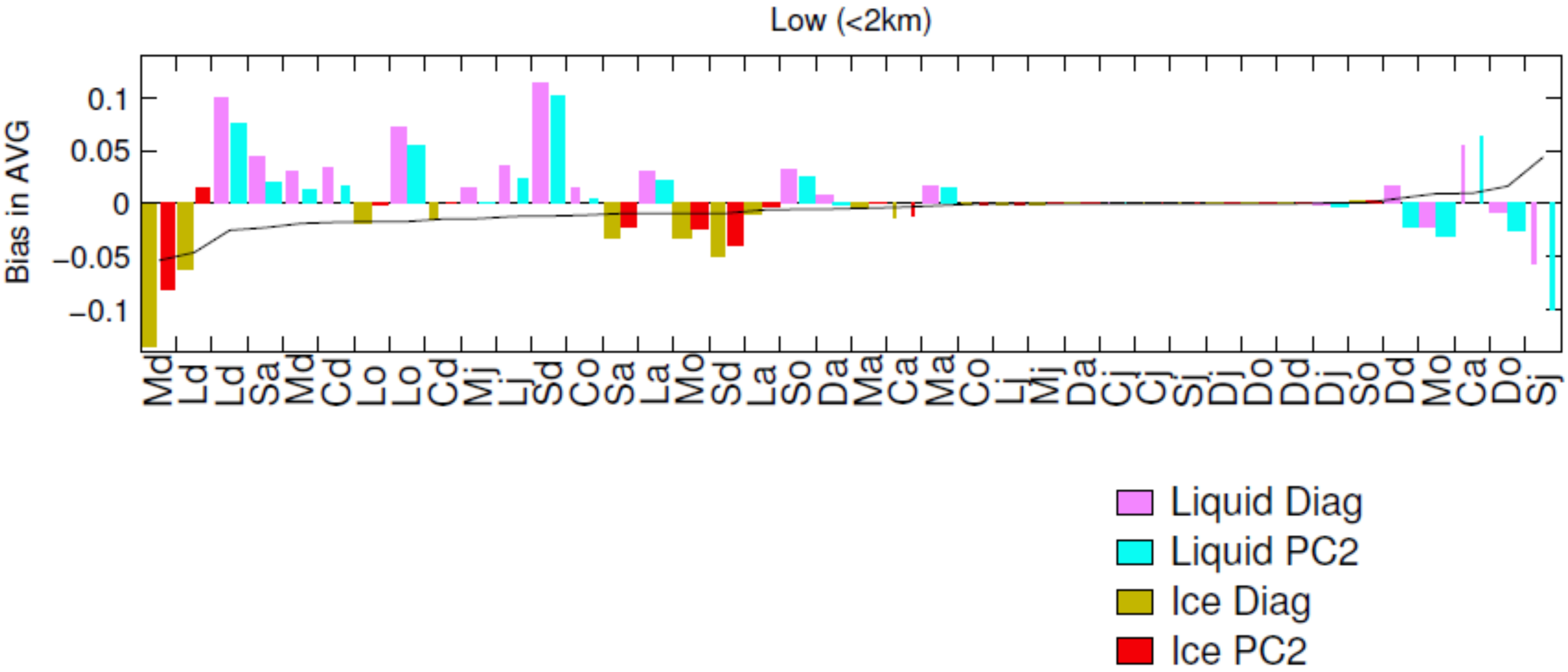
Morcrette, O'Connor and Petch (2011) *QJRMS* DOI:10.1002/qj.969

Mean error (bias) in low cloud cover



Is there a way of making this info clearer?

Morcrette, O'Connor and Petch (2011) *QJRMS* DOI:10.1002/qj.969



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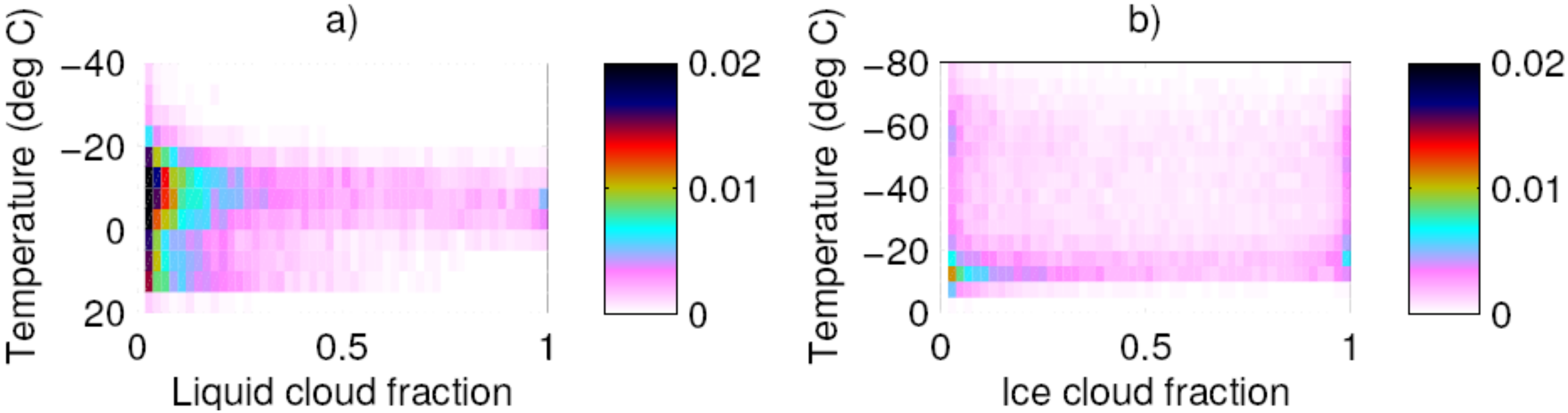


If cloud is present, what is the cloud fraction?

Morcrette, O'Connor and Petch (2011) *QJRMS* DOI:10.1002/qj.969

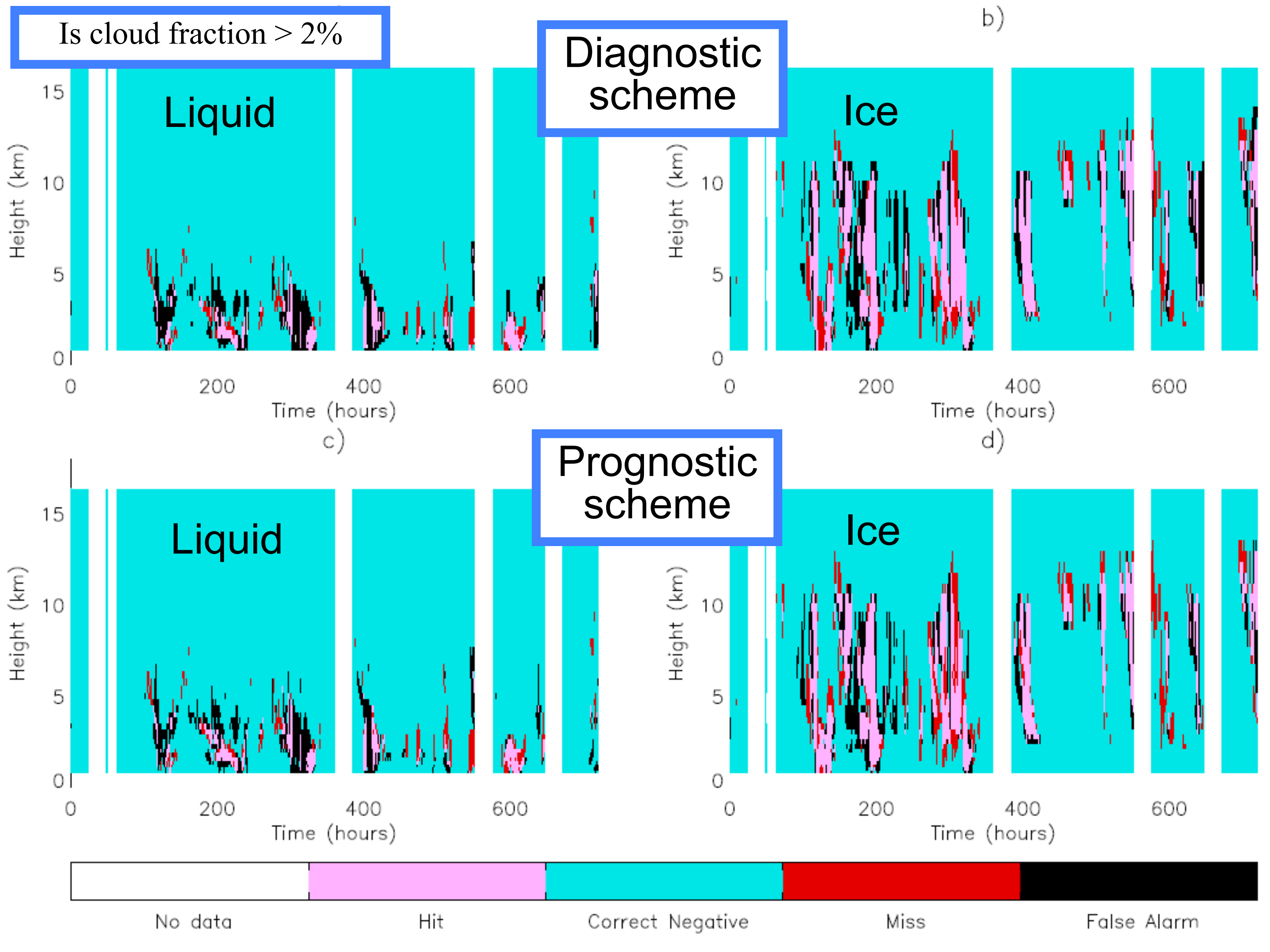
Contingency Table

Select a threshold

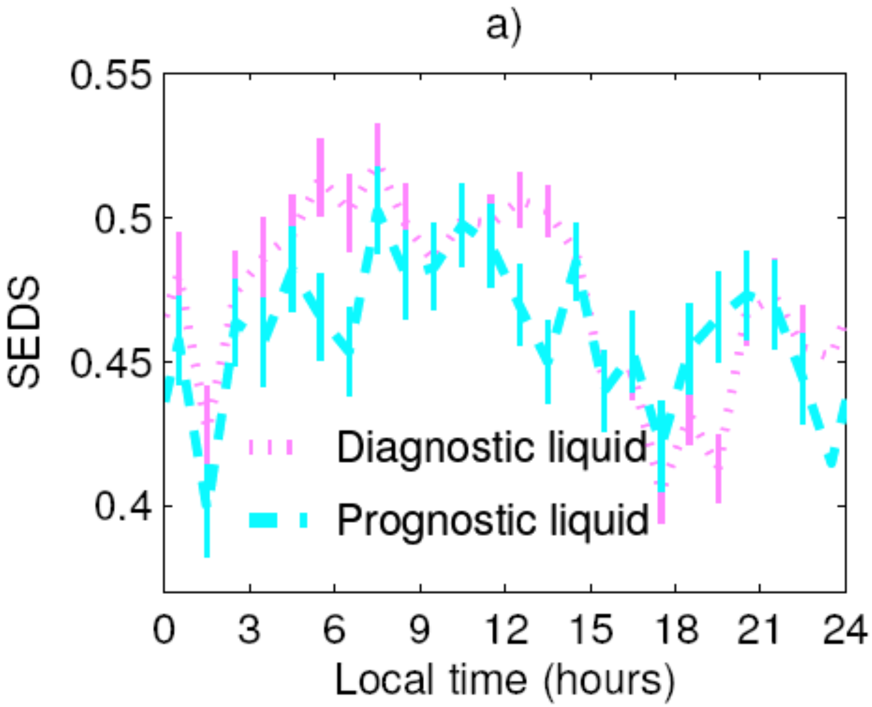
e.g. cloud fraction > 2%

Can do this for **<u>liquid</u>** and **<u>ice</u>** cloud fraction separately.

		Event in observations	
		YES	NO
Event in model	YES	Hit (a)	False alarm (b)
	NO	Miss (c)	Correct negative (d)



Is cloud fraction > 2%
Diagnostic scheme
Prognostic scheme
Liquid
Ice
b)
c)
d)
Height (km)
Time (hours)
0
5
10
15
0
200
400
600
No data
Hit
Correct Negative
Miss
False Alarm


a)
0.55
0.5
0.45
0.4
SEDS
Diagnostic liquid
Prognostic liquid
0
3
6
9
12
15
18
21
24
Local time (hours)

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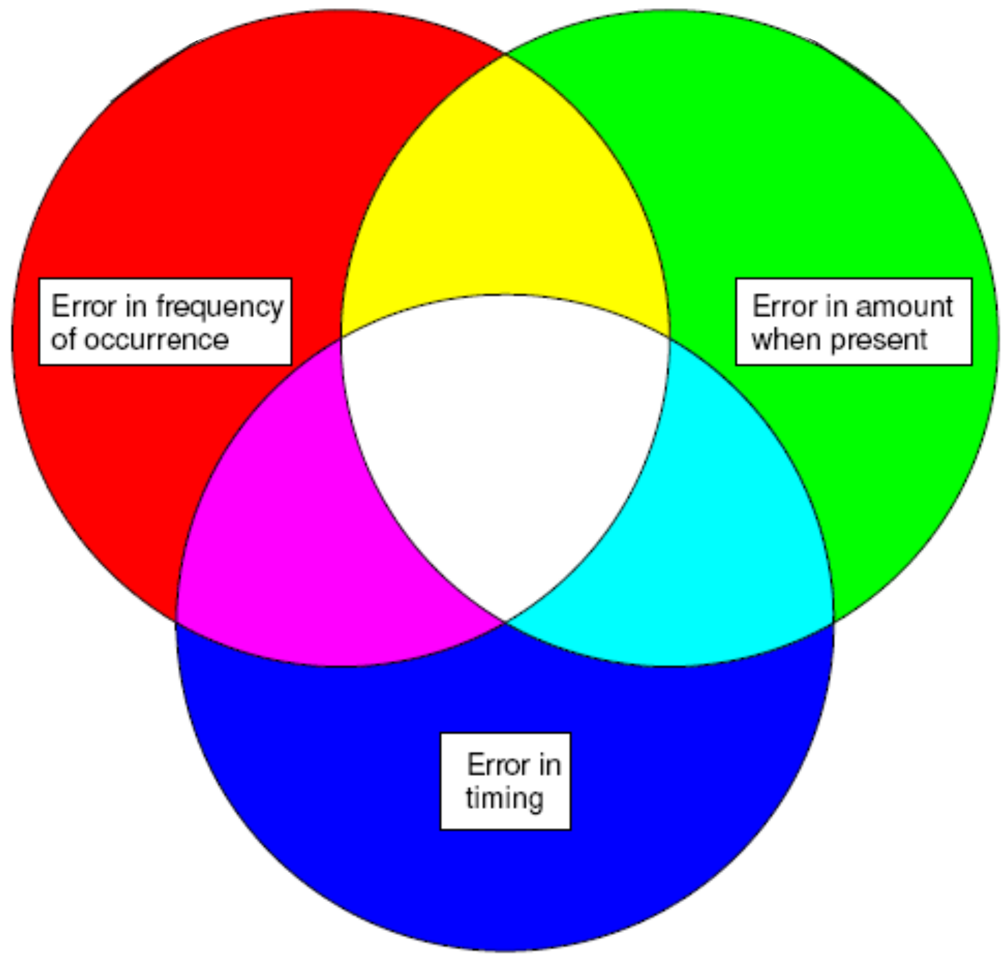
Errors in cloud parametrization scheme

Large-scale errors in T and q

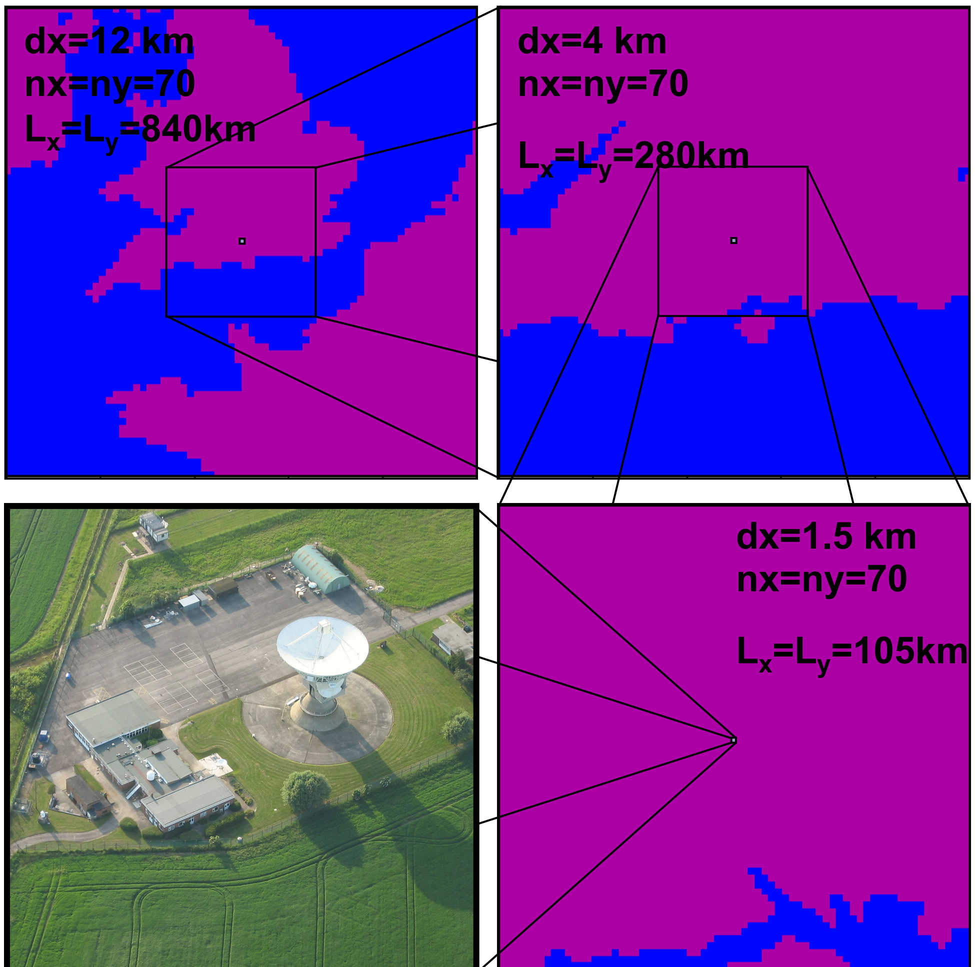
Errors in other parametrization schemes

There are different types of cloud errors…

… and they are caused by different things.



Clouds in 12, 4 and 1.5 km models



The 12, 4 and 1.5 km nest centred over Chilbolton, England.

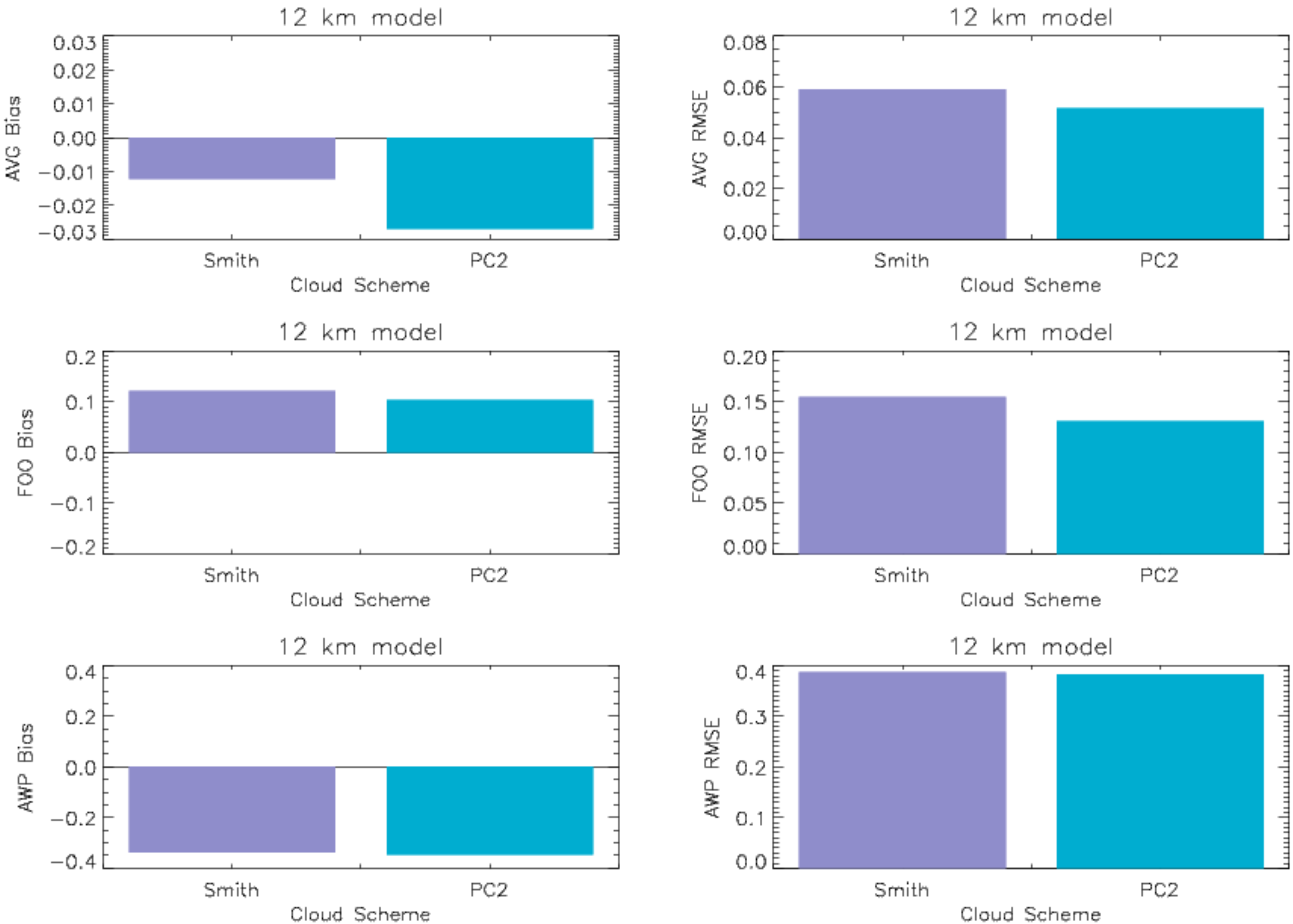
At present:

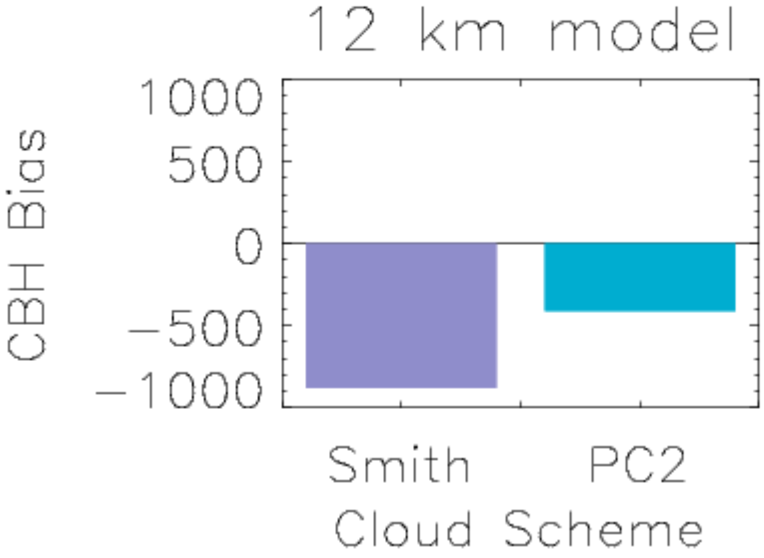
- **New** scheme has replaced the old in:
  - global forecasting and ensembles
  - seasonal prediction and
  - in development version of model for climate change studies
- **Old** scheme still used in:
  - 12-km limited area model (North-Atlantic and Europe)
  - 4 km UK model.
  - 1.5 km UK model.
- Should the new scheme be used in these higher resolution models?
- Use radar/lidar obs to find what is the “best” cloud scheme to use in 12, 4 and 1.5 km models.

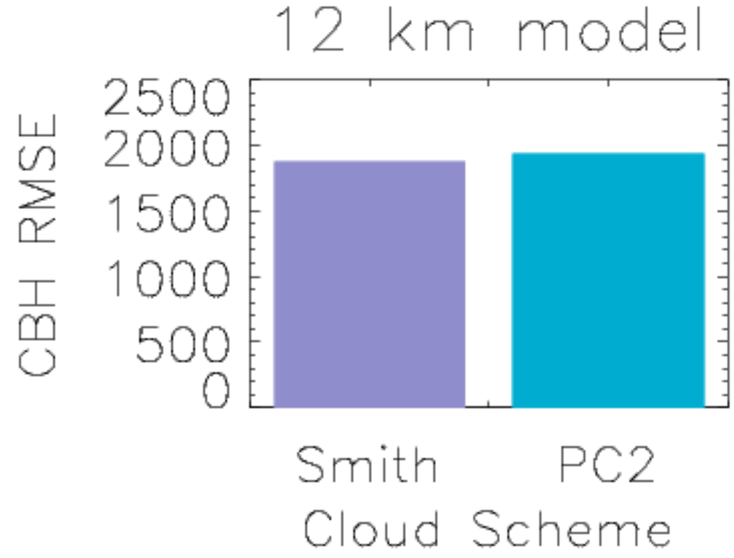
Note: “Convection” (represented by the convection scheme) is one of the main sources of cloud (in the global model at 40 km).

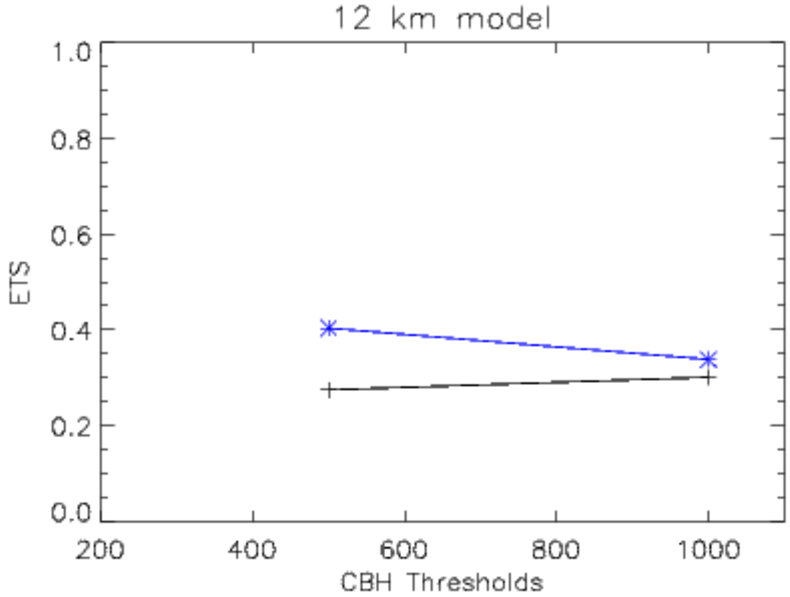
The 1.5 km model does not use a convection scheme, so how will the PC2 cloud scheme perform in that situation…?

12-km model results


12 km model
AVG Bias
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
AVG RMSE
0.08
0.06
0.04
0.02
0.00
FOO Bias
0.2
0.1
0.0
−0.1
−0.2
FOO RMSE
0.20
0.15
0.10
0.05
0.00
AWP Bias
0.4
0.2
0.0
−0.2
−0.4
AWP RMSE
0.4
0.3
0.2
0.1
0.0
Smith
PC2
Cloud Scheme



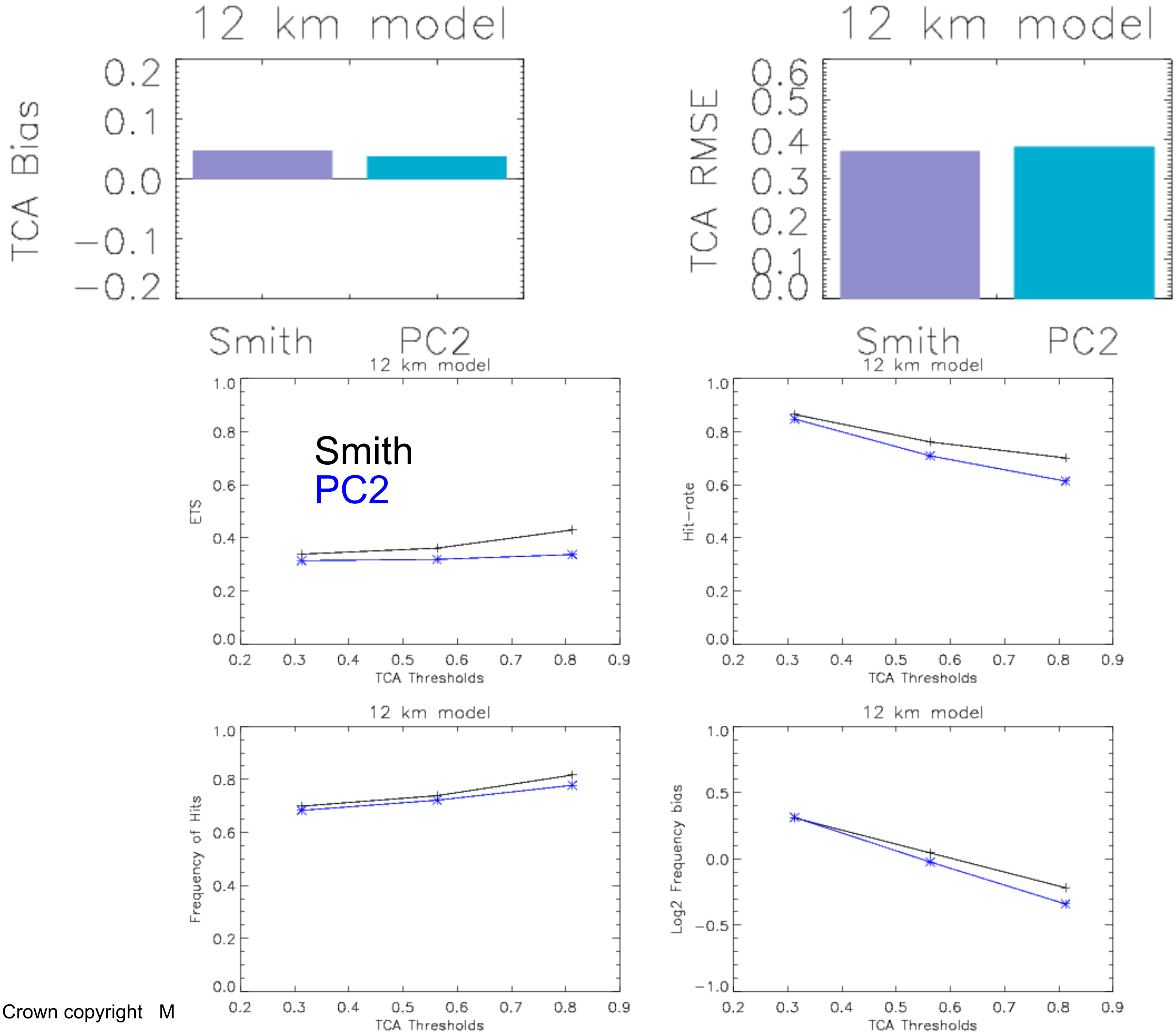




Smith

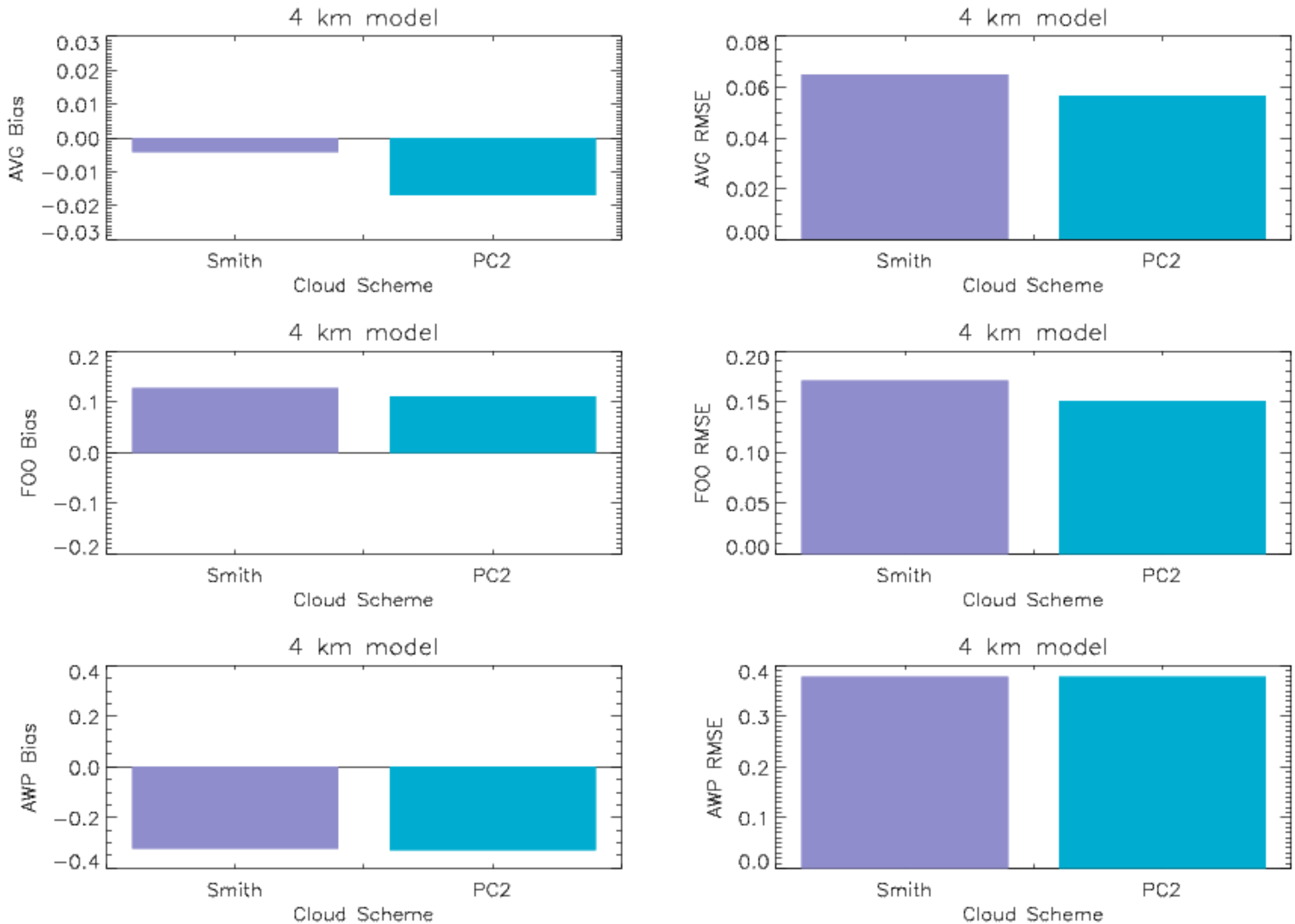
PC2

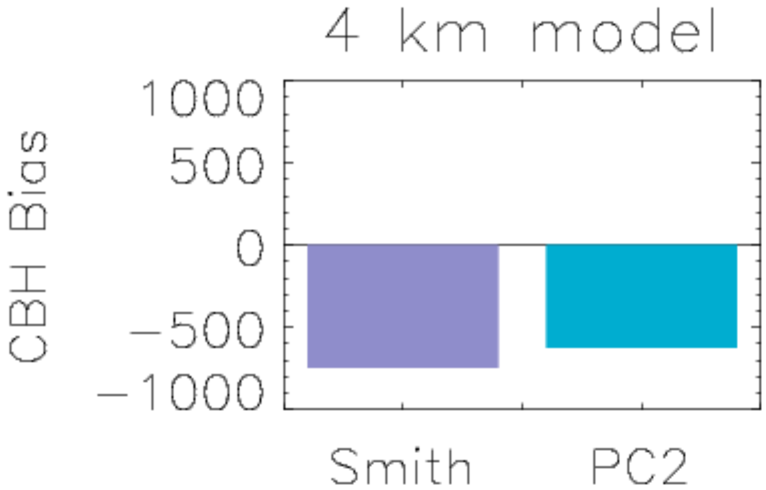
PC2 is “better”

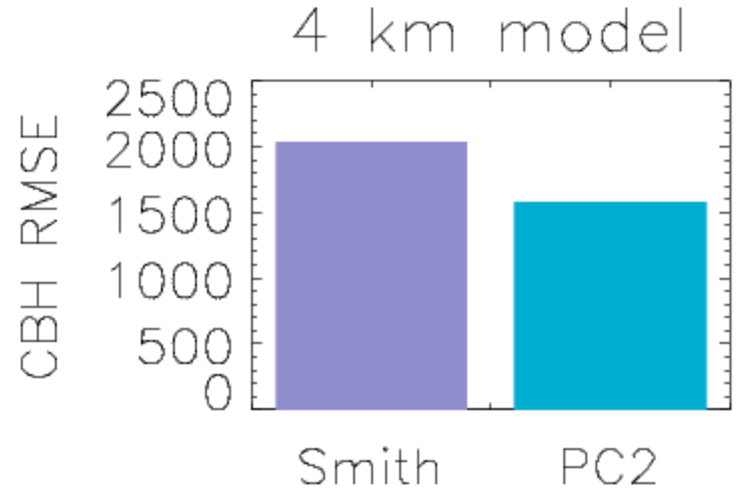


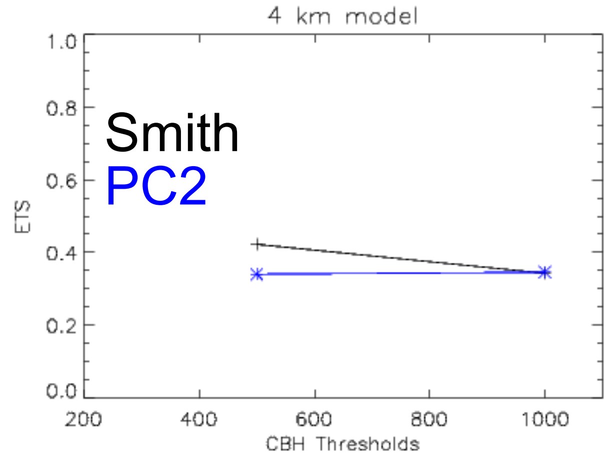
12 km model
TCA Bias
0.2
0.1
0.0
−0.1
−0.2
Smith
PC2
12 km model
TCA RMSE
0.6
0.5
0.4
0.3
0.2
0.1
0.0
Smith
PC2
12 km model
ETS
Smith
PC2
TCA Thresholds
12 km model
Hit−rate
TCA Thresholds
12 km model
Frequency of Hits
TCA Thresholds
12 km model
Log2 Frequency bias
TCA Thresholds

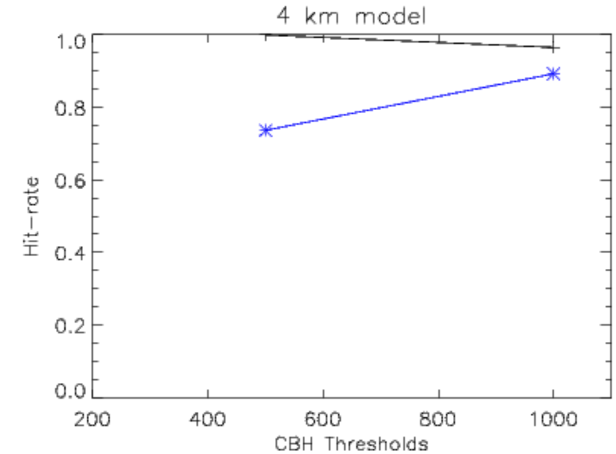
4-km model results


4 km model
AVG Bias
0.03
0.02
0.01
0.00
−0.01
−0.02
−0.03
Smith
PC2
Cloud Scheme
4 km model
AVG RMSE
0.08
0.06
0.04
0.02
0.00
Smith
PC2
Cloud Scheme
4 km model
FOO Bias
0.2
0.1
0.0
−0.1
−0.2
Smith
PC2
Cloud Scheme
4 km model
FOO RMSE
0.20
0.15
0.10
0.05
0.00
Smith
PC2
Cloud Scheme
4 km model
AWP Bias
0.4
0.2
0.0
−0.2
−0.4
Smith
PC2
Cloud Scheme
4 km model
AWP RMSE
0.4
0.3
0.2
0.1
0.0
Smith
PC2
Cloud Scheme

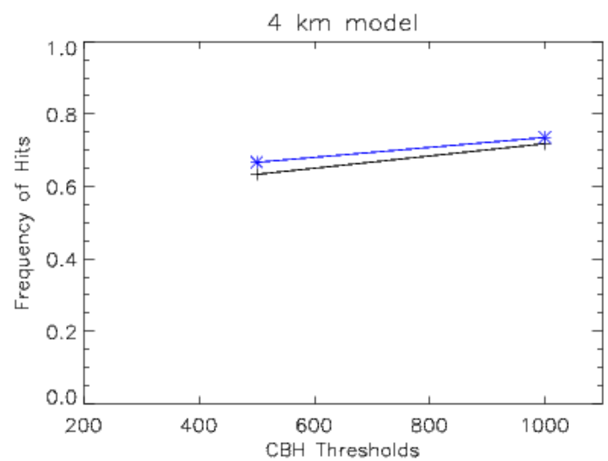


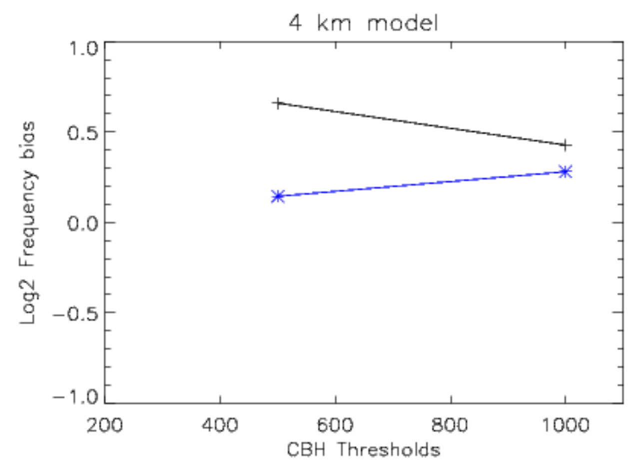


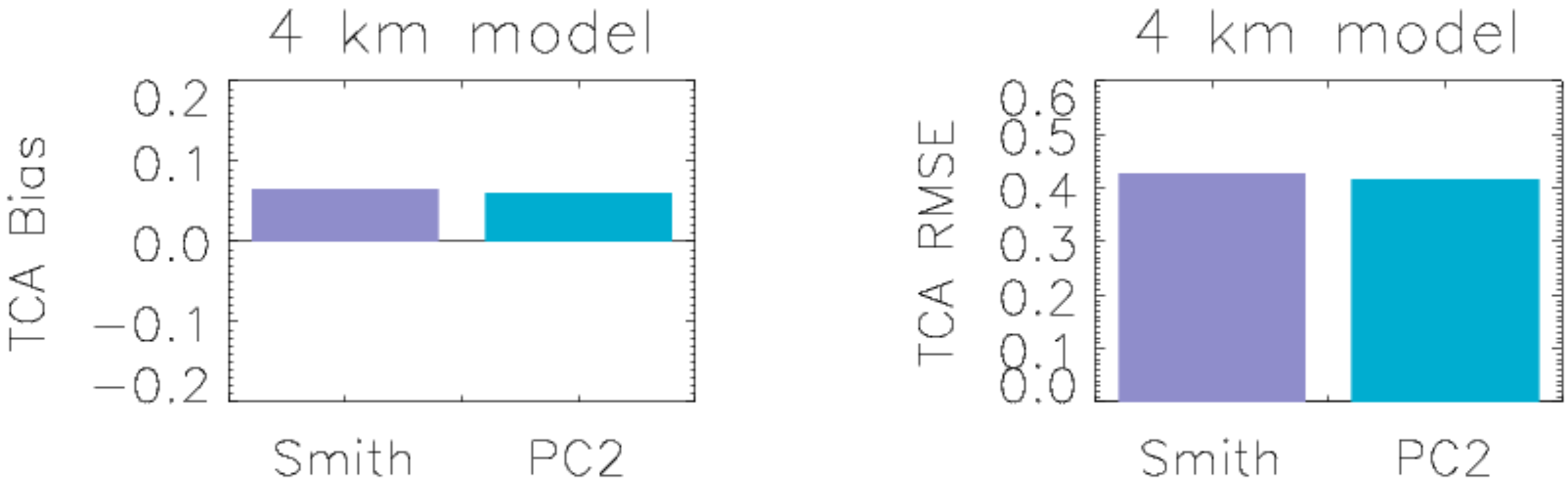




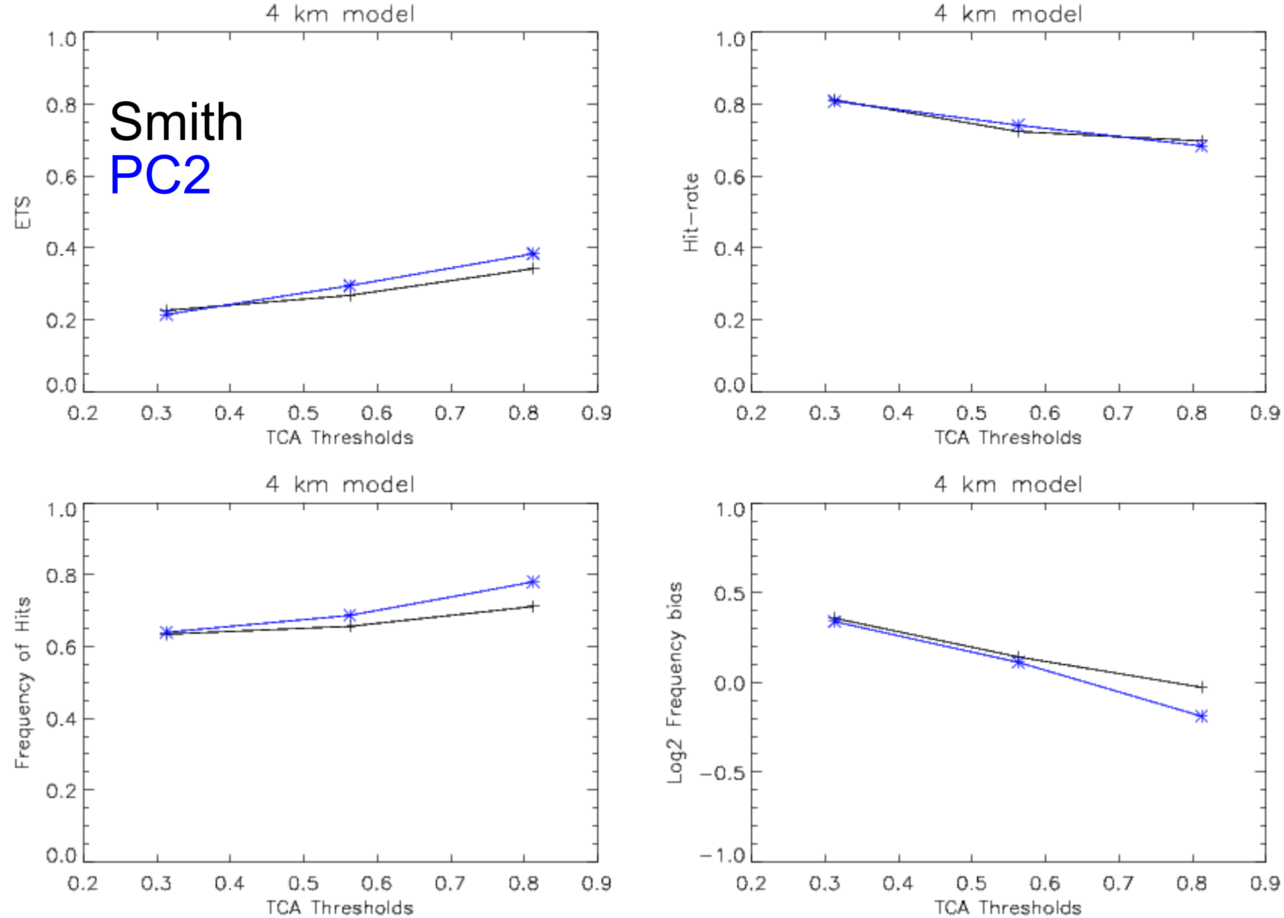
Freq bias reduced, less obs events forecast but more of fc events are correct.







4 km model
TCA Bias
Smith
PC2
4 km model
TCA RMSE
Smith
PC2



4 km model
ETS
Smith
PC2
TCA Thresholds
4 km model
Hit-rate
TCA Thresholds
4 km model
Frequency of Hits
TCA Thresholds
4 km model
Log2 Frequency bias
TCA Thresholds

Conclusions

•Clouds are an important part of the weather and climate system.

•In the models used for weather forecasting and climate studies, clouds are represented using parametrization schemes.

•Development of new schemes requires evaluation and comparison of new scheme with its predecessor.

•Remote-sensing observations provide an essential data-set with which to evaluate the models.

•Determining which scheme is the "best" can be tricky. There are different aspect to "getting it right".

•A scheme can perform quite well in spite of, or due to, its compensating errors. This is "getting the mean cloud right for the wrong reasons".

•A more physically-realistic scheme, which addresses some of the compensating errors, can then appear to perform worse.

•So in order to understand how the performance of the cloud schemes differ, one needs to look at a variety of metrics, not just the standard skill scores or time-averaged cloud fields.

Questions